View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Northumbria Research Link

Northumbria Research Link

Citation: Winnard, Andrew, Debuse, Dorothee, Wilkinson, Mick, Tahmosybayat, Robin and Caplan, Nick (2017) The immediate effects of exercise using the Functional Re-adaptive Exercise Device on lumbopelvic kinematics in people with and without low back pain. Musculoskeletal Science and Practice, 27 (S1). S47-S53. ISSN 2468-7812

Published by: Elsevier

URL: https://doi.org/10.1016/j.msksp.2016.11.011 <https://doi.org/10.1016/j.msksp.2016.11.011>

This version was downloaded from Northumbria Research Link: http://nrl.northumbria.ac.uk/30018/

Northumbria University has developed Northumbria Research Link (NRL) to enable users to access the University's research output. Copyright © and moral rights for items on NRL are retained by the individual author(s) and/or other copyright owners. Single copies of full items can be reproduced, displayed or performed, and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided the authors, title and full bibliographic details are given, as well as a hyperlink and/or URL to the original metadata page. The content must not be changed in any way. Full items must not be sold commercially in any format or medium without formal permission of the copyright holder. The full policy is available online: http://nrl.northumbria.ac.uk/policies.html

This document may differ from the final, published version of the research and has been made available online in accordance with publisher policies. To read and/or cite from the published version of the research, please visit the publisher's website (a subscription may be required.)

www.northumbria.ac.uk/nrl

northumbria UNIVERSITY NEWCASTLE

Note: this is the final draft of the article:

Winnard, A., Debuse, D., Wilkinson, M., Tahmosybayat, R. & Caplan, N.

The immediate effects of exercise using the Functional Re-adaptive Exercise Device on lumbopelvic kinematics in people with and without low back pain.

Musculoskeletal Science and Practice 2017; in press

In: *Musculoskeletal Science and Practice* Supplement on: "Terrestrial neuro-musculoskeletal rehabilitation and astronaut reconditioning: reciprocal knowledge transfer"

Guest Editors: Stokes M, Evetts S, Hides J.

Accepted: 13th November 2016 for publication in *Musculoskeletal Science and Practice*

Please use the following link for the final, fully proofed and peer-reviewed journal article online: http://www.manualtherapyjournal.com/

In: *Musculoskeletal Science and Practice*Supplement: "Terrestrial neuro-musculoskeletal rehabilitation and astronaut reconditioning: reciprocal knowledge transfer" Guest Editors: Maria Stokes, Simon Evetts, Julie Hides

The immediate effects of exercise using the Functional Re-adaptive Exercise Device on lumbopelvic kinematics in people with and without low back pain

Winnard, A., Debuse, D., Wilkinson, M., Tahmosybayat, R. & Caplan, N.

Faculty of Health and Life Sciences, Northumbria University, Newcastle upon Tyne, United Kingdom

Corresponding author:

Dr Nick Caplan
Faculty of Health and Life Sciences
Northumbria University
Northumberland Building
Newcastle upon Tyne
NE1 8ST
Tel: +44 (0)191 243 7382
Email: nick.caplan@northumbria.ac.uk

Keywords:

Motor control
Lordosis
Lumbopelvic kinematics
Functional Re-adaptive Exercise Device

Abstract

Background

Dysfunction of the lumbar multifidus (LM) and transversus abdominis (TrA) muscles is associated with low back pain (LBP). The Functional Re-adaptive Exercise Device (FRED) has shown potential as a non-specific LBP intervention by automatically recruiting LM and TrA. Loss or lordosis and altered lumbopelvic positioning has also been linked to LBP and is often trained within LM and TrA interventions. The effect that FRED exercise has on lumbopelvic positioning and lumbar lordosis is unknown.

Objectives

To assess the effect of FRED exercise on lumbopelvic kinematics and alignment to establish whether FRED exercise promotes a favourable lumbopelvic posture for training LM and TrA.

Design

Within and between-group comparison study

Method

One hundred and thirty participants, 74 experiencing LBP, had lumbopelvic kinematic data measured during over-ground walking and FRED exercise. Magnitude-based inferences were used to compare walking with FRED exercise within participants and between the asymptomatic and LBP groups, to

establish the effects of FRED exercise on lumbopelvic kinematics, compared to walking, in each group.

Results

FRED exercise promotes an immediate change in anterior pelvic tilt by 8.7 degrees compared to walking in the no-LBP and LBP groups. Sagittal-plane spinal extension increased during FRED exercise at all spinal levels by 0.9 degrees in the no-LBP group, and by 1.2 degrees in the LBP group.

Conclusions

FRED exercise promotes a lumbopelvic position more conducive to LM and TrA training than walking in both asymptomatic people and those with LBP.

Highlights

- A posture conducive to LM and TrA training was promoted.
- The posture appears to occur automatically in people with and without LBP.
- Exercise on the FRED may be effective for LM and TrA training.

1. Introduction

Muscular deconditioning due to physical inactivity has been linked with increased risk of non-specific low back pain (LBP) in the general population (Verbunt et al., 2010). Direct costs of LBP within the UK were estimated as £1 billion per year (NICE, 2009), demonstrating a need for effective countermeasure and rehabilitation interventions.

Non-specific LBP has no single known cause or specific causative pathology (Balague et al., 2012). However, changes in spinal mechanics have been reported as a common element (Panjabi, 2006). Altered spinal mechanics and LBP have been linked with atrophy (Hides et al., 2008a; Danneels et al., 2000; Hodges et al., 2006; Hodges & Richardson, 1996; Ferriera et al., 2004) and altered motor control (Hodges & Richardson, 1996) of the lumbar multifidus (LM) and transversus abdominis (TrA) muscles. Atrophy of LM and TrA has also been associated with loss of lordosis, development of back pain and spinal injury, and following periods of low activity and disuse of spinal muscles (Buckey, 2006; Hides et al., 2011; Sayson & Hargens, 2008).

Due to gravitational unloading of the spine in astronauts, and the reduced level of deep spinal muscle activity required to maintain upright posture, atrophy of the deep spinal muscles, similar to that seen in LBP, has been reported following as little as two weeks of exposure to microgravity (Evetts et al., 2014). It is also evident that astronauts lose control of the lumbar lordosis during

spaceflight (Buckey, 2006). Muscle atrophy and altered motor control have been specifically observed in the lumbopelvic region (Sayson and Hargens 2008) and 12 out of 20 astronauts reported LBP during spaceflight (Snijders et al. 2011). Johnston et al. (2010) also reported that astronauts had a more than four-fold increased risk of herniated disc pulposus within the first year following spaceflight, compared with controls Astronauts must undergo intensive reconditioning upon return to Earth in order to restore muscle size and function, and to reduce the risk of spinal injury (Hides et al., 2015; Lambrecht et al., 2016), using similar methods employed in the general population (Hides et al., 2016; Stokes et al., 2016). Winnard et al. (2016) identified the need for exercise interventions for reconditioning and that rigorous studies were needed, using standardised outcome measures (Beard & Cook, 2016).

Specific motor control training is an evidence-based approach to the rehabilitation of LM and TrA function (Hodges et al., 2013; Hides et al., 2010; Hides, 2013; Hodges et al., 2013), and is currently used as part of astronaut reconditioning by the European Space Agency (Evetts et al., 2014; Lambrecht et al., 2016). It involves progressive training, beginning with isolating muscle recruitment, followed by recruitment during upright, functional positions while maintaining lumbar lordosis and thoracic kyphosis (Hides et al., 2008b; O'Sullivan, 2000). This requires conscious effort by the patient in order to recruit LM and TrA deliberately and develop or maintain the required posture. What complicates this approach is that many people with and without LBP find it difficult to selectively activate LM and TrA (Van et al., 2006). Therefore,

clinicians have tried to employ strategies that make it easier for people with LBP to recruit these muscles. Increased LM activity has been reported when a lumbar lordosis is present which extends throughout the lumbar region to the thoracolumbar junction (Roussouly et al., 2005; O'Sullivan et al., 2006). Claus et al. (2009) found that increasing anterior pelvic tilt up to the point of achieving a lordosis up to the thoracolumbar junction resulted in the highest measured activity of both TrA and LM compared to slumped and hyperlordotic (extended into the thoracic spine) postures. Therefore, the maintenance of a lumbar lordosis is a cornerstone of specific motor control training (O'Sullivan et al., 2006; Claus et al., 2009; Roussouly et al., 2005).

Recently, Debuse et al. (2013) investigated a new exercise device, the Functional Re-adaptive Exercise Device (FRED)(Figure 1), that has been designed to recruit the LM and TrA muscles. FRED exercise requires the user to perform slow controlled cyclical movement of the feet against no external resistance, necessitating active control of motion by both legs (Debuse et al., 2013). The rearward leg must work to prevent an uncontrolled descent of the forward foot through the front of the movement cycle. Throughout exercise, the user is encouraged to maintain a stable upper body.

[Insert Figure 1 near here]

FRED exercise has already been suggested to automatically recruit both LM and TrA (Debuse et al., 2013) without users' voluntary control. It results in LM and TrA activity that is more tonic than walking (Caplan et al., 2014) and

increases lumbopelvic stability when compared to over-ground walking (Gibbon et al., 2013). However, the immediate effect of FRED exercise on lumbopelvic kinematics in asymptomatic people or those with LBP has not yet been investigated. As loss of lordosis has been linked to LM and TrA atrophy (Buckey, 2006; Hides et al., 2011; Sayson & Hargens, 2008), this study aimed to determine the immediate effect of FRED exercise on lumbopelvic kinematics in the sagittal plane in people with and without LBP.

2. Materials and Methods

2.1. Participants

One-hundred-and-thirty participants took part in this within and between-group comparison study, recruited from the general public; they had a mean±SD age, height and mass of 35.2±11 years 1.72±0.09 m, and 76.8±17.1 kg, respectively. The study was open to the general public to participate, as an interactive science museum activity, and anyone visiting the museum could ask to participate. Therefore inclusion bias was minimised as museum attendance could not be directly influenced. Exclusion criteria were being aged under 18 or over 55 years, having a history of neuromusculoskeletal problems or injuries resulting in scoliosis or inability to exercise safely on the FRED, being pregnant, having heart disease and having had abdominal or spinal surgery in last three years. All participants were required to pass the Physical Activity Readiness Questionnaire (Kent, 2006) prior to testing. The sample was divided into two groups, those with and those without back pain as determined a chartered physiotherapist, allowing comparison of variables between people with and

without LBP. Back pain screening was based on question 7 from the short form 36 (SF-36), standard, US version 2 (QualityMetric, 2000) (see Table 1). Low-back-pain scores of 2 or more indicated that participants had LBP. Based on this screening, there were 56 participants with LBP and 74 without. The study was ethically approved by the institutional ethics committee and all participants gave fully-informed-written consent to take part.

[Insert Table 1 near here]

2.2. Data collection

Lumbopelvic kinematics during over-ground walking and FRED exercise were assessed using a wearable motion capture system (MVN, XSens, Enschede). The system consists a series of motion tracking devices placed at key areas within a wearable suit that was placed over participants t-shirt and trousers, in line with published guidelines (Roetenberg et al., 2013). Data from the motion trackers was applied to a full body biomechanical model that derives orientations of, and joint angles between, all body segments. The system measured flexion/extension at segment junctions that simulate L5/S1, L3/L4, T12/L1 and T8/T9 and orientation of the pelvis for anterior pelvic tilt. These estimated angles were selected to provide an indication of lumbar lordosis, lower thoracic kyphosis and sagittal plane pelvic tilt which, as mentioned earlier, is an important aspect of specific motor control training.

The XSens motion capture system consists of 17 sensors that each contain a 3D gyroscope, 3D accelerometer and a magnetometer. The sensors are secured to the hands, forearm, upper arm, head, shoulder blades, pelvis, upper leg, lower leg and feet with neoprene bands and Velcro straps. The sensors were placed over each participant's clothing. To minimise movement artefacts from clothing, sensors were only placed over a single layer of clothing and participants were asked to remove any coats or jumpers. Participants were also required to remove footwear throughout the trials to prevent any confounding effect of footwear design, including heel height.

Full body kinematic data were collected at 120 Hz, using the default full-body model and Kinematic Coupling Algorithm (KiC) fusion engine setting, without magnetometer data (to minimise errors from any magnetic interference). Kinematic data were downlinked in real time to a PC running MVN studio 3.1 (XSens, Enschede) and applied to a 3D avatar consisting of 23 rigid segments linked by joints (pelvis, L5, L3, T12, T8, neck, head, shoulders, arms, hands, legs, feet, toes), which was used to calculate all kinematic outputs (Roetenberg et al., 2013). The same XSens was used for all participants, trackers were placed over anatomical landmarks and the straps adjusted to ensure a secure positioning. Participant's height was measured and used to automatically scale the digital avatar within the MVN software, accounting for variation in size across the participants. For modelling the segments of interest within spine, data were taken from trackers placed on the sacrum, sternum, scapulae and head. The locations of the trackers are show in Figure 2. The spine was

divided into segments with joints estimating movements at L5S1, L3L4, L1T12 and T9T8. The movement of these joints was estimated by the software using interpolation between the trackers. This is the default setup of the system as per the XSens user manual, which states that the segment definitions were matched to International Society of Biomechanics recommendations (XSens, 2012). The default spinal model is displaced based on the tracker data, and the amount of movement divided over segment joints based on an assigned stiffness of each segment set within the software.

[Insert figure 2 near here]

The XSens setup used had previously been reported as having up to two degrees error for dynamic accuracy in roll, pitch and heading linked to pelvic tilt data, and an angular resolution for joint angle estimation of 0.05 degrees (Lebel et al., 2013). The XSens system has been validated against the VICON 3D motion analysis system which is considered the 'gold standard' for measuring kinematic data (Roetenberg et al., 2013). The default XSens setup has been shown to have good correlation with optical motion capture systems for estimated 3D kinematics at the L5S1 level (Faber et al., 2016). A further detailed overview of the default XSens system and software with an example of its use for estimating lower limb functional movements was presented by Koning et al. (2015).

XSens records change in position of the body from calibration. Therefore, results show changes in variables between walking and FRED exercise rather than indicating true spinal positioning, or spinal position relative to a normal reference range. Walking was chosen for the comparisons as it is another functional upright exercise/activity, but one which is not a specific motor control exercise. Therefore, comparisons with walking show whether FRED promotes any lumbopelvic kinematic elements that may be beneficial to specific motor control training compared to a common, regular upright functional activity.

2.3. Protocol

First, kinematic data during over-ground walking along a straight and level walkway were collected, allowing a minimum of two complete gait cycles to be captured. Following this, participants were given a five minute familiarisation period exercising on the FRED before twenty seconds of kinematic data during FRED exercise were collected, during which a minimum of five complete FRED cycles occurred. The exercise involved cyclical feet movements while weight – bearing on an unstable base of support in upright posture. Real time feedback is provided to promote a smooth, controlled cyclical motion at a target frequency of 0.4Hz. Movement amplitude on the FRED was set to the smallest amplitude setting (0.2 m). The researcher explained the FRED in-built visual feedback to help users maintain a steady speed and even movement.

2.4. Data analysis

Magnitude-based inference (MBI) statistics were used to run multiple pairwise comparisons for each kinematic variable between FRED exercise and walking and comparing the LBP and no-LBP groups. The difference in mean spinal position and pelvic tilt between the LBP and no-LBP groups was entered into the analysis. These statistics provide the probability for each comparison that the true (population) change is positive, negative or trivial with reference to a pre-determined minimal worthwhile change. This allows an inference on how meaningful any population difference is (Batterham & Hopkins, 2006). In the absence of a previously reported and validated minimal clinically meaningful change on which to base inferences, a standardised mean change between comparisons of at least 0.2 Cohen units was considered worthwhile, as this shows that at least a small effect size exists between two comparison groups (Batterham and Hopkins 2006). This allowed comparisons to be assessed based on the probability of a true measurable change occurring. The standardised mean change based on Cohen's *d* was calculated as:

$$d = \frac{sample\ mean1 - sample\ mean2}{pooled\ standard\ deviation\ of\ sample\ 1\ and\ 2}$$

The raw change, standardised mean change with 90% confidence intervals and probabilities (%) that the true values were mechanistically positive, trivial or negative were then reported as defined by Hopkins et al. (2008), where <0.5% is *"most unlikely*", <5% is "*very unlikely*", <25% is "*unlikely*", 25-75% is "*possibly*", >75% is "*likely*", >95% is "*very likely*", and >99.5% is "*most likely*". The mechanistic inference is based on threshold chances of 5% for substantial

magnitudes. The same MBI was used to assess the chance (%) of any differences in demographics between the LBP and no-LBP groups being trivial. In comparisons where variation made small inferences unclear, the worthwhile change threshold was increased to the lowest level which produced a clear result, of either 0.6 or 1.2, which showed at least moderate and large effect sizes respectively (Hopkins et al., 2008). All threshold changes were highlighted in the results. All variables were compared between FRED exercise and walking. The results of the LBP and no-LBP group were also compared using MBI statistics to test for any differences in a clinically relevant population.

3. Results

Any differences in the demographics between the LBP and no-LBP group were trivial (Table 2).

[Insert Table 2 near here]

[Insert figures 3 & 4 near here]

[Insert Tables 3 & 4 hear here]

Spinal joint angles

FRED exercise increased extension at all estimated spinal levels compared to walking, in both groups, with the highest magnitude occurring at the L5/S1 level

(Figure 3). The increase in extension was estimated to be 0.9-1.2 degrees at L5/S1 and 0.3-0.4 degrees at T8/T9. There was also a weak trend that the estimated extension was less in the no-LBP group, by 0.3 degrees at L5/S1 and 0.1 degrees at T8/T9. It was at least *very likely* that FRED exercise resulted in increased extension, compared to walking, at all spinal levels (Table 3). It was at best *possible* that the no-LBP group had slightly less extension at all levels than the LBP group.

Anterior pelvic tilt

FRED exercise resulted in increased anterior pelvic tilt compared to walking, with the increase being 8.7 degrees in both the LBP and no-LBP groups (Figure 4). There was a *most likely* increase in anterior pelvic tilt in both groups and that any difference between the LBP and no-LBP group was *trivial* (Table 4).

4. Discussion

The main finding of this study was that FRED exercise results in increased anterior pelvic tilt and estimated spinal extension compared to over-ground walking. The increase in extension was highest at L5 where it was estimated to be 0.9±2.2 degrees in the no-LBP group. The increase was slightly more (greater than the no-LBP group by 0.1-0.3 degrees) in the LBP group. Participants were not provided with instructions or feedback regarding pelvic tilt or spinal curves during exercise. Therefore, the kinematic effects reported

during FRED exercise appear to have occurred automatically, possibly without participants consciously altering their lumbopelvic position. Further research is required to confirm the potential involuntary nature of these changes.

A shift of sagittal spine joint angles towards extension, seen mostly in the lower lumbar spine, suggests participants' lordosis angle was increasing. It is unknown from this study if an ideal position of lordosis up to thoracolumbar junction occurred, because the motion capture system used does not measure or estimate absolute position of the joints or relative to a normal or vertical reference. Small extension increases were still estimated at T8/T9 which may indicative of a hyperlordotic position.

Debuse et al. (2013) found that FRED exercise recruits LM and TrA. Postures which increase anterior pelvic tilt and increase lordosis extending no further than the thoracolumbar junction have been linked to increased LM and TrA recruitment (O'Sullivan et al., 2006; Roussouly et al., 2005). Additionally, hyperlordotic postures extending lordosis beyond the thoracolumbar junction have been shown to decrease LM and TrA activity (Claus et al., 2009). Therefore, the estimated lordosis increase seen in FRED exercise is likely to be within the range that facilitates LM and TrA activation and not result in hyperlordosis. The small amount of estimated increase in lordosis (0.5-1 degree), and it being mostly in the lower lumbar spine, further suggests this postural change was within the range required for LM and TrA to be active.

Caplan et al. (2014) reported that LM activity on FRED was tonic throughout the exercise, whereas walking resulted in a biphasic recruitment pattern with peaks around heel strike and toe off. As the superficial fibres of LM have a role in lordosis control (Macintosh et al., 1986; Musculino, 2005; Moseley et al., 2002), a tonic LM contraction in FRED exercise compared to walking (Caplan et al., 2014) may also partly explain why increased lordosis and anterior pelvic tilt was found throughout FRED exercise compared to walking.

Training LM and TrA, while maintaining lumbar lordosis and thoracic kyphosis, is an element of specific motor control exercise (Hides et al., 2008b; O'Sullivan, 2000). FRED exercise has already been shown to automatically recruit LM and TrA (Debuse et al., 2013). The present study suggests FRED exercise also automatically promotes a lumbopelvic position conducive to LM and TrA recruitment. FRED exercise may, therefore, be beneficial for the rehabilitation of people with LBP, and the prevention of LBP. The latter is particularly in view of evidence that shows that lordosis decreases in low-activity populations which suffer disuse atrophy of LM and TrA resulting in increased risk of spinal injury and pain (Buckey 2006; Hides et al. 2011; Sayson and Hargens 2008). The capacity of FRED exercise to automatically promote increased lordosis, therefore, suggests it may be a useful intervention for both training LM and TrA as part of a rehabilitation programmes for LBP and for improving lubopelvic position, including recovery of lumbar lordosis. It could also be a relevant reconditioning tool for use in astronauts following exposure to microgravity,

where the deep lumbopelvic muscles are known to be atrophied (Hides et al., 2015; Evetts et al., 2014; Hides et al., 2007).

Our findings show that only very small differences in estimated sagittal spinal extension between the LBP and no-LBP groups were *possible,* and the differences in pelvic tilt between the two groups were *trivial*. Therefore, the lumbopelvic position promoted by FRED exercise was the same in the LBP and no-LBP groups. This suggests that the immediate effects of one-off FRED exercise are very similar in people with and without LBP. Whilst the estimated changes in sagittal spinal kinematics at individual vertebral levels were small, they were much higher than the reported measurement error of the system used (Lebel et al., 2013). It must be noted, however, that the errors reported by Lebel et al. (2013) were determined for controlled conditions and not during dynamic activities as used here, so it would be important to confirm that the magnitude of errors reported previously are appropriate. The changes seen at individual vertebral levels would equate to an estimated increase of approximately 5 degrees across all lumbar levels combined (assuming a similar increase of approximately 1 degree at each lumbar level). Normal range of spinal extension has been reported as being 19 degrees in the lumbar spine (Joseph et al., 2001), suggesting that FRED exercise facilitates increased spinal extension of approximately 25% of this range. Further work is required, however, to determine the clinical relevance of these small changes.

As the kinematic changes measured during FRED exercise in non-symptomatic individuals are likely to be linked to involuntary (but very welcome) (Debuse et al., 2013) tonic LM and TrA activity (Caplan et al., 2014) , this suggests the same muscle activity occurred in those participants in this study with LBP. This may be an indication that FRED exercise is effective as an intervention for tonic recruitment and training of LM and TrA in people with LBP. The estimated increase in lordosis in the LBP group was slightly higher than in the no-LBP group. This may indicate the device was producing a slightly larger effect in the LBP group which could occur if they had more varied spinal mechanics as is often found in LBP (Panjabi, 2006).

4.1. Limitations of the study

The LBP group consisted mostly of individuals who indicated experiencing very mild to moderate LBP. However, only six participants indicated experiencing severe or very severe pain. Therefore, the LBP results are mostly representative of populations with very mild to moderate back pain and should, therefore, not be applied to those with severe or very severe pain.

As the motion capture system used was unable to produce results with reference to a normal spinal posture or vertical reference, the analysis only showed how FRED exercise compares to walking. It is unknown whether participants had normal, hyper- or hypo-lordotic postures originally. Sub-grouping participants based on a postural analysis may have shown if FRED exercise had any potential to correct poor postures towards an optimal spinal

position for training LM and TrA. Although participants were grouped as either having LBP or no LBP, the multifactorial nature of non-specific LBP means they could have been either hyper- or hypo- lordotic (Claus et al., 2009; O'Sullivan et al., 2006). However, previous studies have shown that FRED exercise automatically recruits LM and TrA (Debuse et al., 2013), and that hyper- and hypo-lordotic postures reduce LM and TrA activity (Claus et al., 2009). This supports the suggestion that FRED exercise could be useful in the restoration of LM and TrA function. As only kinematic changes were determined between walking and FRED exercise, reference data from, for example, upright standing were not available. As such, it is also not known whether the 5 minute familiarisation period on the FRED could, itself, have led to kinematic changes in the recording period that were not seen in the walking data due to there being no walking familiarisation period. Further research should, therefore, determine the influence of familiarisation time on the kinematics of FRED exercise.

This study only considered the immediate effects of one-off FRED exercise, and this may have been why no changes were seen between the LBP and no-LBP groups. It may be that during initial periods of exercise on the device, individuals with LBP can achieve as good a technique as their non-symptomatic peers, but this may change over time as a result of fatigue (Ament & Verkerke, 2009). The average familiarisation and fatigue points of non-symptomatic people and those with LBP during FRED exercise should be determined in future investigations.

5. Conclusions

Using the FRED increases anterior pelvic tilt and estimated spinal extension, mostly at the lower lumbar spine level around L5, compared to walking. There was a weak trend that this increase was slightly greater in the LBP group, which may be due to greater spinal kinematic variation often found in this population. The amount of increase in anterior pelvic tilt and spinal extension suggested that FRED exercise automatically promotes lumbar lordosis and may facilitate a spinal position conducive to the recruitment of LM and TrA. The lack of any *likely* difference between the LBP and no-LBP groups suggested that the immediate effects of one-off FRED exercise are very similar for people with and without LBP. This finding may be indicative of the potential for FRED exercise to be an effective LM and TrA training intervention in both non-symptomatic and LBP populations. Future investigations should examine the longer-term effects of FRED exercise, both during a single exercise session and as part of a rehabilitation intervention.

6. References

Ament, W. & Verkerke, G., 2009. Exercise and Fatigue. *Sports Medicine*, 39(5), pp.389-422.

Balague, F., Mannion, A.F., Pellise, F. & Cedraschi, C., 2012. Non-specific low back pain. *Lancet*, 379, pp.482-91.

Batterham, A.M. & Hopkins, W.G., 2006. Making Meaningful Inferences About Magnitudes. *International Journal of Sports Physiology and Performance*, 1, pp.50-57.

Beard, D. & Cook, J., 2016. Methodology for astronaut reconditioning research. *Manual Therapy Supplement on "Terrestrial neuro-musculoskeletal rehabilitation and astronaut reconditioning: reciprocal knowledge transfer*, xx, pp.xx-xx.

Buckey, J.C., 2006. *Space Physiology*. 1st ed. New York: Oxford University Press.

Caplan, N., Gibbon, K.C., Hibbs, A. & Debuse, D., 2014. Phasic-to-tonic shift in tunk muscle activity during low-impact weight bearing exercise. *Acta Astronautica*, 104, pp.388-95.

Claus, A.P., Hides, J.A., Moseley, L.G. & Hodges, P.W., 2009. Different Ways to Balance the Spine. *SPINE*, 34, pp.208-14.

Danneels, L.A. et al., 2000. CT imaging of trunk muscles in chronic low back pain patients and health control subjects. *European Spine Journal*, 9, pp.266-72.

Debuse, D., Birch, O., Gibson, A.S.C. & Caplan, N., 2013. Low impact weight-bearing exercise in an upright posture increases the activation of two key local muscles of the lumbo-pelvic region. *Physiotherapy Theory and Practice*, 29(1), pp.51-60.

Evetts, S. et al., 2014. Post Space Mission Lumbo-Pelvic Neuromuscular Reconditioning: A European Perspective. *Aviation, Space and Environmental Medicine*, 85(7), pp.764-65.

Ferriera, P.H., Ferreira, M.L. & Hodges, P.W., 2004. Changes in Recuitment of the Abdominal Muscles in People with Low Back Pain. *SPINE*, 29(22), pp.2560-66.

Gibbon, K.C., Debuse, D. & Caplan, N., 2013. Low impact weight-bearing exercise in an upright posture achieves greater lumbopelvic stability than overground walking. *Journal of Bodywork & Movement Therapies*, 17, pp.462-68.

Hides, J., 2013. The relationship between control of the spine and low back pain: a clinical researcher's perspective. In *Spinal Control: The Rehabilitation of Back Pain*. Edinburgh: Churchill Livingstone.

Hides, J.A. et al., 2007. Magnetic Resonance Imaging Assessment of Trunk Muscles During Prolonged Bed Rest. *SPINE*, 32(15), pp.1687-92.

Hides, J., Gilmore, C., Stanton, W. & Bohlscheid, E., 2008a. Multifidus size and symmetry among chronic LBP and healthy asymptomatic subjects. *Manual Therapy*, 13, pp.43-49.

Hides, J.A. et al., 2011. The effects of rehabilitation on the muscles of the trunk following prolonged bed rest. *European Spine Journal*, 20, pp.808-18.

Hides, J. et al., 2016. Parallels between astronauts and terrestrial patients – taking physiotherapy rehabilitation “To Infinity and Beyond”. *Manual Therapy Supplement on "Terrestrial neuro-musculoskeletal rehabilitation and astronautr reconditioning*, xx, pp.xx-xx.

Hides, J., Lambrecht, G., Stanton, W. & Damann, V., 2015. Changes in multifidus and abdominal muscle size in response to microgravity: possible implications for low back pain research. *European Spine Journal*, p.pre publication.

Hides, J. et al., 2008b. Effect of Stabilisation Training on Multifidus Muscle Cross-sectional Area AMong Young Elite Cricketers With Low Back Pain. *Journal of Orthopaedic & Sports Physical Therapy*, 38(3), pp.101-08.

Hides, J. et al., 2010. Retraining motor control of abdominal muscles among elite cricketers with low back pain. *Scandinavian journal of medicine & science in sports*, 20(6), p.8340842.

Hodges, P., Holm, A.K., Hannson, T. & Sten, H., 2006. Rapid Atophy of the Lumbar Multifidus Follows Experimental Disc or Nerve Root Injury. *SPINE*, 25, pp.2926-88.

Hodges, P.W.l. & Richardson, C.A., 1996. Inefficient Muscular Stabilization of the Lumbar Spine Associated With Low Back Pain: A Motor Control Evaluation of Transversus Abdominis. *Spine*, 21(22), pp.2640-50.

Hodges, P. et al., 2013. Integrated clinical approach to motor control interventions in low back pain and pelvic pain. In UK, ed. *Spinal Control: The Rehabilitation of Back Pain*. 310: Elsevier. p.243.

Hopkins, W.G., Marshall, S.W., Batterham, A.M. & Hanin, J., 2008. Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Medicine & Science in Sports & Exercise*, 41(1), pp.3-12.

Johnston, S., Campbell, M., Scheuring, R. & Feiveson, A., 2010. Risk of hernated nucleus pulposus among US astronauts. *Aviation, Space and Environments Medicine*, 81(6), pp.566-74.

Joseph, K., Kippers, V., Richardson, C. & Panianpour, M., 2001. Range of Motion and Lordosis of the Lumbar Spine Reliability of Measurement and Normative Values. *Spine*, 26, pp.53-60.

Kent, M., 2006. *The Oxford Dictionary of Sports Science & Medicine*. 3rd ed. Oxford University Press.

Lambrecht, G. et al., 2016. The role of Physiotherapy in the European Space Agency strategy for preparation and reconditioning of astronauts. *Manual Therapy - Supplement on "Terretrial*

neuro-musculoskeletal rehabilitation and astronaut reconditioning: reciprocal knowledge transfer", xx, pp.xx-xx.

Lebel, K., Boissy, P., hamel, M. & Duval, C., 2013. Inertial Measure of Motion for Clinical Biomechanics: Comparative Assessment of Accuracy under Controlled Conditions - Effect of velocity. *PLOS One*, 8(11).

Lower, C., 2014. Quaternion to Euler conversion. p.Personal communication.

Macintosh, J., Valencia, F., Bogduk, N. & Munro, R., 1986. The morphology of the human lumbar multifdus. *Clinical Biomechanics*, 1(4), pp.196-204.

Moseley, L., Hodges, P. & Gandevia, S., 2002. Deep and Superficial Fibers of the Lumbar Multifidus Muscle Are Differentially Active During Voluntary Arm Movements. *SPINE*, 27(2), pp.29-136.

Musculino, J.E., 2005. *The Muscular System Manual*. 2nd ed. St Lewis, Missouri: Elsevier.

NICE, 2009. Low Back Pain. Early management of persistent non-specific low bac pain. *NHS NICE website*, Last accessed 21st Febuary 2014 at www.nice.org.uk.

NICE, 2013. *Assessment and prevention of falls in older people*. Manchester: National Institue for Health and Care Excellence.

O'Sullivan, P.B., 2000. Lumbar segmental "instability": clinical presentation and specific stabilizing exercise management. *Manual Therapy*, 5(1), pp.2 - 12.

O'Sullivan, 2005. Diagnosis and classification of chronic low back pain disorders: Maladaptive movement and motor control impairments as underlying mechanism. *Manual Therapy*, 10, pp.242-55.

O'Sullivan, P.B. et al., 2006. Effect of Different Upright Sitting Postures on Spinal Pelvic Curvature and Trunk Muscle Activation in a Pain-Free Population. *SPINE*, 31(19), pp.707-12.

Panjabi, M.M., 2006. A hypothesis of chronic back pain: ligament subfailure injuries lead to muscle control dysfunction. *European Spine Journal*, 15, pp.668-76.

QualityMetric, 2000. *SF-36v2 Health Survey*. http://www.sf-36.org/: Medical Outcomes Trust.

Roetenberg, D., Luinge, H. & Slycke, P., 2013. Xsens MVN: Full 6DOF Human Motion Tracking Using Miniature Inertial Sensors. *XSENS TECHNOLOGIES*, pp.1-9.

Roussouly, P., Gollogly, S., Berthonnaud, E. & Dimnet, J., 2005. Classfication of the Normal Variation in the Sagittal Alignment of the Human Lumbar Spine and Pelvis in the Standing Postition. *SPINE*, 30(3), pp.346-53.

Rubenstein, 2006. Falls in older people: epidemiology, risk factors and strategies for prevention. *Age and Ageing*, 35(S2), pp.ii37-41.

Sayson, J. & Hargens, A., 2008. Pathophysiology of Low Back Pain during Exposure to Microgravity. *Aviation, Space and Environmental Medicine*, 79, pp.365-73.

Snijders, C.J. et al., 2011. Low Back Pain during Flight - 1 Year Post-Flight Science Report. *European Space Agency Report*, ESA Proposal number 2003-DSM-MUS-100.

Stokes, M., Evetts, S. & Hides, J., 2016. Guest Editorial - Terrestrial neuro-musculoskeletal rehabilitation and astronaut reconditioning: reciprocal knowledge transfer. *Manual Therapy Supplement on "Terrestrial neuro-musculoskeletal rehabilitation and astronaut reconditioning: reciprocal knowledge transer"*, xx, pp.xx-xx.

Van, K., Hides, J. & Richardson, C., 2006. The use of real-time ultrasound imaging for biofeedback of lumbar multifidus muscle contraction in healthy subjects. *The Journal of orthopaedic and sports physical therpay*, 36(12), pp.920-25.

Verbunt, J.A., Smeets, R.J. & Wittink, H.M., 2010. Cause of effect? Deconditioning and chronic low back pain. *PAIN*, 149, pp.428-30.

Winnard, A. et al., 2016. Systematic Review of countermeasures to minimise physiological changes and risk of injury to the lumbopelvic area following long-term microgravity. *Manual Therapy Supplement on "Terrestrial neuro-musculoskeletal rehabilitation and astronaut reconditioning: reciprocal knowledge transfer"*, xx, pp.xx-xx.

XSens, 2012. *MVN User Manual*. Enschede, NL: XSens.

Tables

Table 1 Low-back pain screening scale and numbers screened to each category

Question: "How much back pain have you had during the past 4 weeks?		n
1	None	74
2	Very mild	17
3	Mild	16
4	Moderate	17
5	Severe	4
6	Very severe	2

Table 2 Group demographics and chance that any group differences are trivial using an inference threshold of 0.6 standardised mean change.

Group	n	Gender (M/F)	Age (years)	Mass (kg)	Height (m)	BMI
LBP	56	30/26	35.4±10.4	78.9±19.1	1.75±0.09	25.8±5.1
No-LBP	74	33/41	35.2±11.3	74.7±14.8	1.72±0.08	25.3±3.6
Chance (%) that difference between groups is trivial			100%	99%	99%	100%

Table 3. Difference in lower spinal sagittal extension angles for all comparisons, calculated with threshold for inferences of 0.2 standardised mean change. For no LBP vs LBP, a negative inference indicates that the variable was smaller in the LBP group

Joint angle	Comparison	Standardised mean change	90% Confidence limits		Mechanistic inference
L5-S1	FRED vs walking, no-LBP	0.4	0.2	0.6	Very likely +ve
	FRED vs walking, LBP	0.6	0.3	0.8	Most likely +ve
	No-LBP vs LBP	-0.1	-0.4	0.2	Possibly -ve
L3-L4	FRED vs walking, no-LBP	0.4	0.2	0.5	Very likely +ve
	FRED vs walking, LBP	0.6	0.3	0.8	Most likely +ve
	No-LBP vs LBP	-0.17	-0.5	0.2	Possibly -ve
T12-L1	FRED vs walking, no-LBP	0.4	0.2	0.6	Very likely +ve
	FRED vs walking, LBP	0.5	0.3	0.7	Very likely +ve
	No-LBP vs LBP	-0.2	-0.5	0.2	Possibly -ve
T8-T9	FRED vs walking, no-LBP	0.4	0.2	0.6	Very likely +ve
	FRED vs walking, LBP	0.6	0.3	0.8	Most likely +ve
	No-LBP vs LBP	-0.2	-0.5	0.2	Possibly -ve

Table 4. Difference in anterior pelvic tilt for all comparisons, calculated with threshold for inferences of 0.2 standardised mean change. [1] indicates threshold for inferences was set to 0.6 standardised mean change. For no-LBP vs LBP, a negative inference indicates that the variable was smaller in the LBP group

Comparison	Standardised mean change	90% Confidence limits		Mechanistic inference
FRED vs walking, no-LBP	2.2	2.0	2.4	Most likely +ve
FRED vs walking, LBP	1.8	1.5	2.0	Most likely +ve
No-LBP vs LBP	0.0	-0.3	0.3	Most likely trivial[1]

Figure Captions

Figure 1. The Functional Re-adaptive Exercise Device

Figure 2. Locations of XSens trackers

Figure 3. Raw change in lower spinal sagittal extension angles comparing walking and FRED exercise in the LBP and no LBP groups individually, and comparing the no LBP and LBP groups for each joint angle.

Figure 4. Raw change anterior pelvic tilt comparing walking and FRED exercise in the LBP (P) and no-LBP (NP) groups individually and comparing the no-LBP and LBP groups for each joint angle.

Figure 1

Figure 2

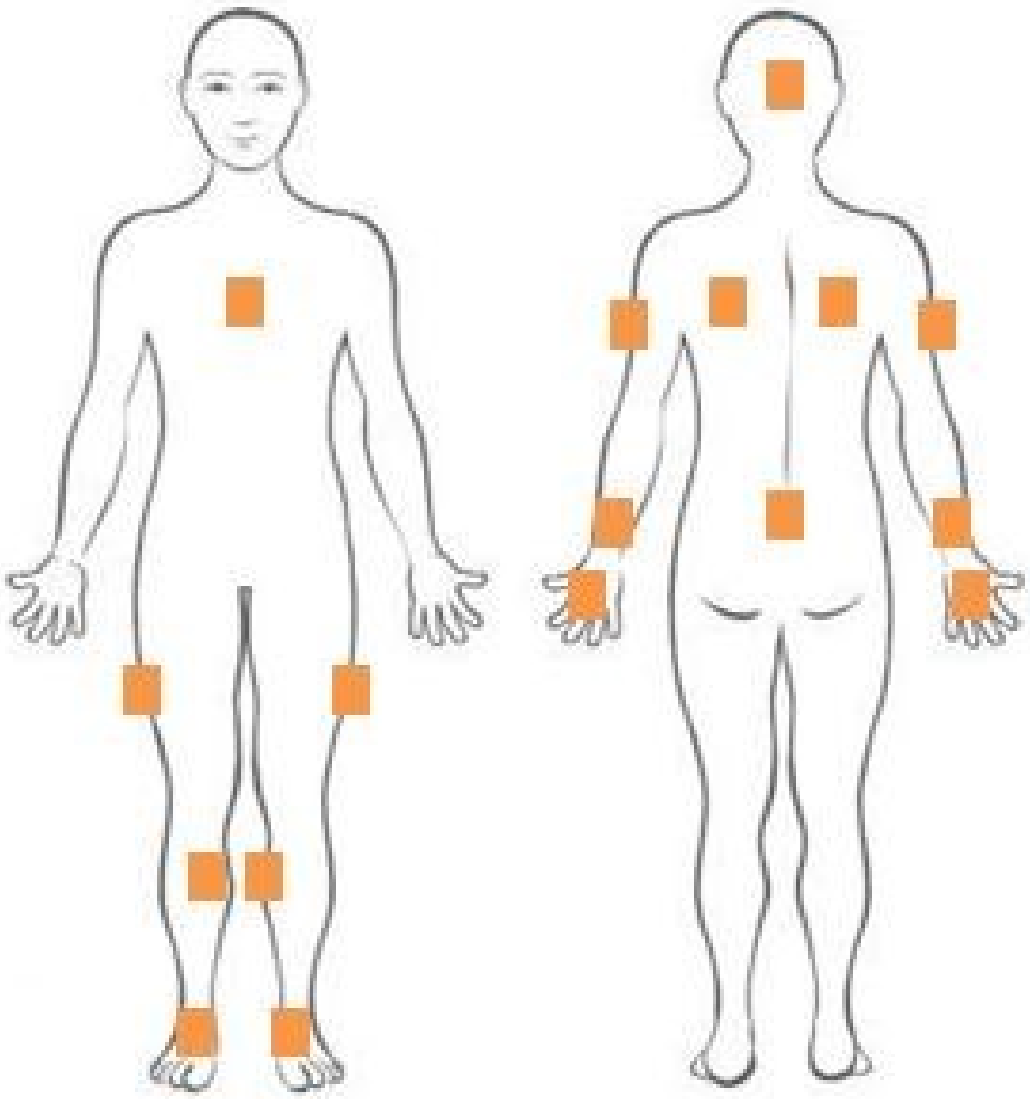


Figure 3

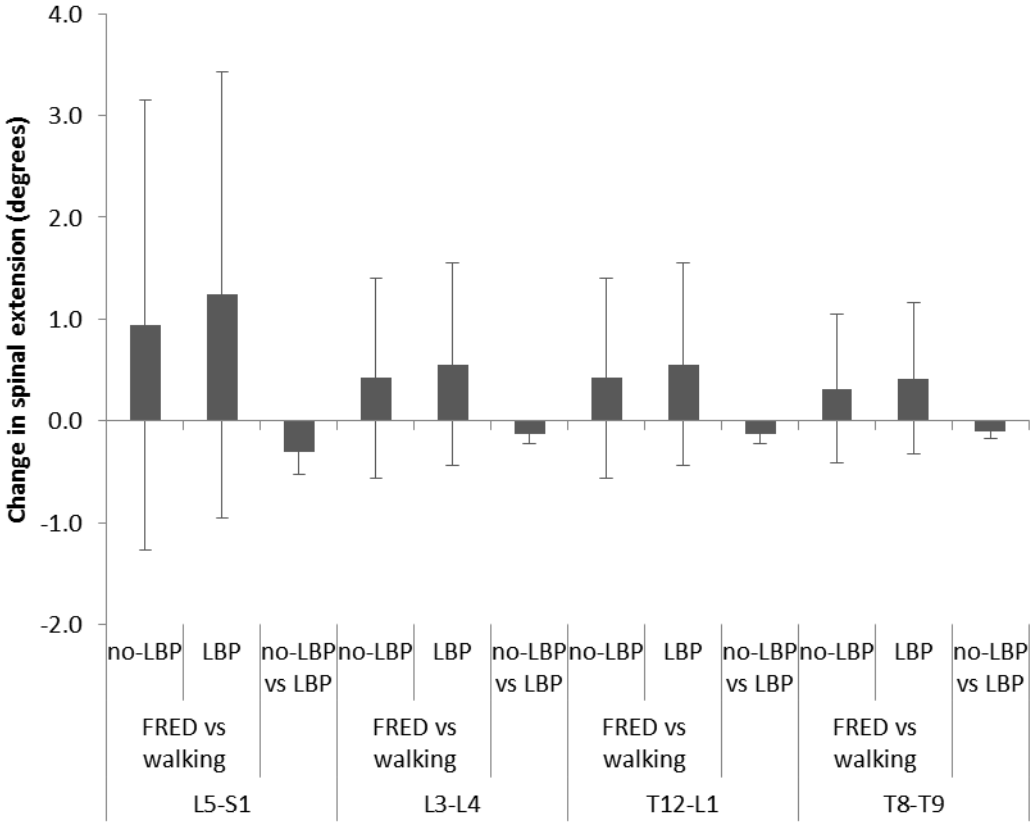
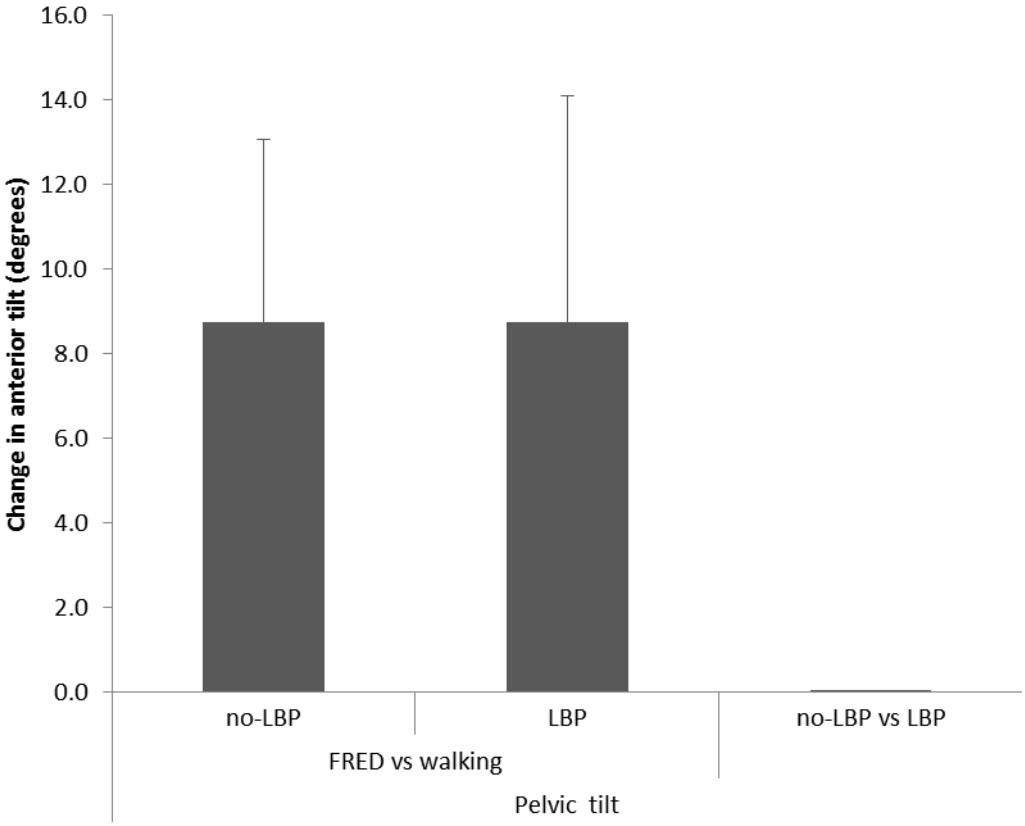

Change in spinal extension (degrees)
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
no-LBP
LBP
no-LBP vs LBP
FRED vs walking
L5-S1
L3-L4
T12-L1
T8-T9

Figure 4


16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Change in anterior tilt (degrees)
no-LBP
LBP
no-LBP vs LBP
FRED vs walking
Pelvic tilt